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(54) Fiber optic fluid sensors.

(57) An optical fluid sensor 20 with a light emitter 2, a photodetector 11 and a sensing tip element 15 which is optically connected by first optical fiber means (4) to the light emitter 2 and by second otpical fiber means (9) to the photodetector 11 is disclosed, said sensing tip element 15 being provided with a coating 14 of a material impermeable by the fluid to be sensed and resistant to the formation of fluid film or droplets thereon thereby reducing undesirable effects or false readings. By constantly monitoring low-level light returned to the photodetector 11 under all operating conditions, the optical fluid sensor of the invention provides a fault finding system.

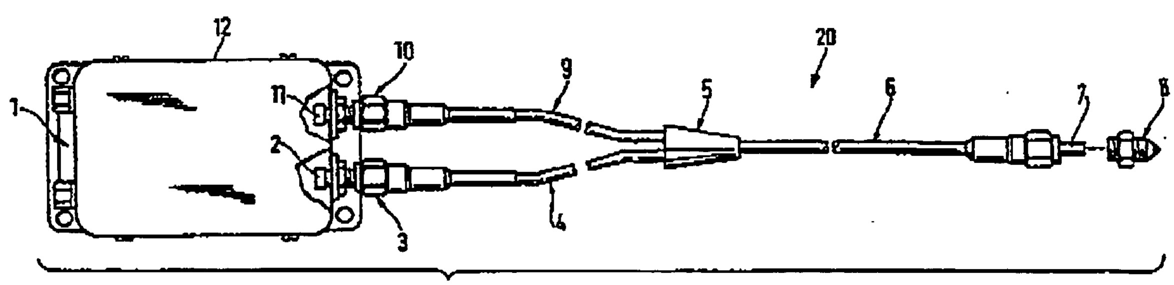

FIG.1

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FIBRE OPTIC FLUID SENSORS

This invention relates to a fiber optic sensing device for sensing the presence, level and/or nature of fluids. It is often necessary or desirable to sense the presence, level and/or other characteristics of fluids. Thus, it is known to use sensors with storage tanks, reservoirs, fuel tanks and pipelines to determine fluid level, conditions of overfill or underfill, or to detect contamination. For example, sensors are used in gasoline storage tanks at service stations to monitor fluid level and to detect contamination in the outer water jacket now commonly installed around such fuel tanks.

Heretofore known sensors rely upon a variety of principles to measure the fluid level and other characteristics. The most common type of sensor is the capacitance type sensor. Unfortunately, these sensors require electrical power at the sensing location, creating a hazard of explosion when volatile fluids are being sensed. Optical sensors also have electrical components in the sensing zone and, thus, suffer from the same explosion hazard. In addition, prior optical sensors have been known to give false indications due to fluids adhering to optical surfaces. Therefore, it is an object of this invention to provide a fluid sensing device capable of performing various sensing functions without presenting any hazard of explosion.

Another object of this invention is to provide a remote fluid sensor in which all electrical components are positioned away from the sensing zone.

Yet another object of the invention is to provide a remote optical sensor which does not suffer from the undesirable effects of fluid films forming at the optical sensing tip.

A still further object of the invention is to provide an optical fluid sensor in which the performance of the sensor components is monitored and a separate output signal provided to indicate failure of any components.

There is provided an optical fluid sensor comprising a light emitter, a photodetector for producing a signal from light incident thereon, a sensing tip including a sensor tip element being in optical communication with said light emitter and said photodetector, characterized in that first optical fiber means are connected to said light emitter and to saidsensing tip for transmitting light from said light emitter to said sensing tip, and second optical fiber means are connected to said sensingtip and to said photodetector, such that light emitted from said emitter is conveyed by said first optical fiber means to said sensing tip, and light returned from said sensing tip is conveyed by said second optical fiber means to said photodetector for detection and processing by electronic processing means, and that said sensing tip is provided with a coating impermeable to the fluid sensed and resistant to the formation of fluid film or droplets thereon and presenting the sensing tip surface in contact with the fluid to be sensed when the said fluid is present.

The aforementioned and other highly desirable and unusual results are accomplished by this invention in an economical structure in which all electrical components are disposed away from the sensing zone with only a non-electrical sensing tip in contact with the fluid in the sensing zone.

In accordance with the invention, an optical fluid sensor is provided which detects the presence, level and/or nature of fluids at a sensing tip by means of optical index of refraction matching between the sensing tip and the fluid.

Advantageously, the invention provides optical sensing at a location remote from the optical emitter, photodetector and associated electronic signal processing equipment. This remarkable advantage is accomplished by providing fiber optic transmission cables between the sensor tip and the emitter and photodetector.

In the sensor according to this invention, light is emitted from a semiconductor light source coupled to an emitter optical fiber, travels through the emitter fiber optic line and is incident on the rear of the sensing tip.

Preferably, the sensing tip has a conical configuration with a coating, such as a thin layer of polytetrafluoroethylene (PTFE), on the outer surface of the tip element itself. At the sensing tip, emitted light is either refracted back into a detector fiber optic cable or is lost, depending upon the relationship between the indices of refraction of the sensing tip and coating to the substance surrounding the sensing tip, i.e., the fluid or air being sensed.

In order to obtain the proper relationship between the sensing tip and the fluid, the index of refraction and the bevel angle of the tip element are carefully selected in relation to the indices of refraction of the coating and the fluid to be sensed. As a result, when fluid surrounds the tip, light is dispersed into the fluid and lost. When no fluid is present, however, the coating sheds any remaining fluid and the light is internally reflected and refracted back into the detector fiber optic cable. Light reflected and refracted back into the detector fiber optic cable is carried by a return fiber cable to a photodetector for sensing and signal processing.

In addition, it has been found that a low level of light is always returned to the photodetector under all conditions. Remarkably, this low level light can be used to monitor the condition of the sensor. For example, in the absence of this constant low level signal a status output can be triggered to indicate that a failure has occurred somewhere in the sensor.

Thus, it can be readily appreciated that this invention provides a sensor capable of determining fluid level or differentiating between fluids based upon the respective indices of refraction of the sensing tip and the fluid(s) being detected.

As a further advantage of the invention this sensing capability is provided without any need for electrical components in the sensing zone, thereby eliminating the serious hazards of explosion which can otherwise occur during the sensing of volatile fluids.

Yet a further remarkable advantage of this invention is that the sensing tip coating reduces the undesirable effects of false readings caused by fluid films formed over the sensor tip.

In addition, the present invention advantageously provides a system fault detector by virtue of the constant monitoring of low-level light returned to the photodetector under all operating conditions.

The accompanying drawings illustrate preferred embodiments of the product of the invention.

Fig. 1 is a top plan view of a preferred embodiment of the invention.

Fig. 2 is a partial cross-section view of the sensor tip according to the invention.

Fig. 3 is an enlarged partial cross-section view of the sensor tip according to the invention illustrating the internal angles of reflection and refraction at the tip element/coating and coating/fluid interfaces.

The drawings show a preferred embodiment of the remote optical sensor constructed in accordance with this invention. In Fig. 1, the fluid sensor 20 includes an electronic module is connected to a power source at electrical connector 1. The electrical power is regulated to provide a constant current to a semiconductor emitter 2, which emits light through an emitter optical connector 3 into a sending fiber cable 4. Sending fiber cable 4 cojoins with return fiber cable 9 at a bifurcation encapsulation 5 to form a fiber cable 6. By way of example only, fiber optic bundles, a duplex pair of fibers or a single fiber provided with a splitter may be used to pro vide the sending and return fiber optic pathways. The choice among these transmission media is governed by such factors as the required transmission distance, optical efficiency, and particular installation requirements.

Sending fiber cable 4 is coupled to a sensing tip 8 by a sensing tip optical connector 7. Sensing tip 8 is installed at the sensing location in contact with the fluid to be sensed. Return optical energy from sensing tip 8 travels through fiber cable 6 and return fiber cable 9 through a detection optical connector 10 to a photodetector 11, where the return signal is detected and electronically processed.

Fig. 2 is a partial cross-section view of sensing tip 8. Light from fiber cable 6 (see Fig. 1) is directed into optical tip 15 to the conical tip 16, where it is refracted into coating 14 at an angle dependent upon the relative indices of refraction of tip element 15 and coating 14.

After passing through coating 14 to the coating/fluid interface the light is refracted into the fluid 22 and lost or is reflected back into the coating 14, depending upon the relative indices of refraction of coating 14 and the fluid 22 being sensed. In the absence of fluid 22 the light is reflected back into coating 14 and again undergoes refraction at the interface of coating 14 and tip element 15. Thereafter, the light travels across tip element 15 perpendicular to the original axis of the light entering tip element 15 from sensing tip optical connector 7 (see Fig. 1) and undergoes a second refraction/reflection process at the other side of the conical tip element 15. The light subsequently reflected and refracted after the second interaction, now travelling in a direction 180° relative to the light entering tip element 15 from sensing element optical connector 7, enters the return fiber of fiber cable 6 through optical connector 7.

Referring again to Fig. 1, the return beam of light travels through fiber cable 6 to bifurcation encapsulation 5, where return fiber cable 9 branches away from sensing cable 4. The return beam of light continues through return fiber cable 9 and photodetector optical connector 10 and is incident upon photodetector 11.

The electrical output of photodetector 11 is proportional to the number of photons of the returned light incident upon the photodetector. The photodetector electrical output signal is amplified and processed by electronics module is in a known manner according to standard output formats. The output signals of electronics module 12 can be transmitted through electrical coupling 1 for display.

Tip element 15 and coating 14 should be constructed of materials carefully selected to have indices of refraction and a tip element bevel angle such that in the presence of the fluid to be sensed light from the sensing tip element 15 will be refracted out into the fluid and lost. In the absence of fluid or in the presence of a second fluid having a different index of refraction the materials selected should cause light to be reflected back in to coating 14, tip element 15 and fiber cable 6 to be detected by photodetector 11.

An important consideration in selecting the coating material 14 is the compatibility of that material with the fluid being sensed. Coating 14 should not degrade in the presence of the fluid being sensed and should shed the fluid so that no fluid droplets or films form over the coating when the fluid level drops. This property is very important since fluid droplets or film can lead to false indications.

Thus, as a practical matter, the coating material is often selected primarily for its durability and ability to shed the fluid. As a result, the index of refraction of the coating material will often be a secondary con sideration in the selection of the coating material and may not be variable by the user.

Thus, there are four primary variables in the sensing tip system as illustrated in Fig. 3.

These are

n_1 -the index of refraction of tip element 15

'a' - the bevel angle of tip element 15

n_2 -the index of refraction of the coating material 14

n_3 -the index of refraction of the fluid 22

In addition, n_3 is considered to be the index of refraction in the absence of fluid. For example, when the fluid level drops and only air surrounds the sensing tip 15, n_3 equals 1.0, the index of refraction of air.

Of the four variables listed above, two are assumed to be fixed while two are variable. First, the index of refraction n_3 of the fluid to be sensed and the index of refraction n_3 of air or a different fluid are determined by the particular application. Therefore, n_3 and n_3 are considered to be invariable. Secondly, since the sensing tip coating 14 is chosen primarily for its properties in relation to the fluid being sensed, i.e. impermeability to the fluid and tendency to shed fluid droplets and/or film, the index of refraction n_2 of this material is also assumed to be invariable.

Therefore, the remaining variables which can be adjusted are the bevel angle 'a' of the sensing tip and the index of refraction n_1 of the tip element.

As a practical matter, in determining the appropriate values for the sensing tip bevel angle 'a' and index of refraction n_1 several factors should be considered. First, the angle of incidence of the light at the coating/fluid interface must be such that the light will be transmitted into the fluid when the fluid is present and will be internally reflected in the absence of fluid. Secondly, when internally reflected light returns from the coating/fluid interface that light must be transmitted from the coating 14 back into the tip element in order to avoid unnecessary loss of light due to trapping in the coating. Third, the sensing tip 15 should be designed to accomodate a small variation in the index of refraction of the fluid, e.g., the index of refraction for JPA jet fuel, one fluid suitable for sensing, has been reported to vary over a range of about 1.40 to 1.45. Fourth, for very sensitive measurements it is contemplated that it may be necessary to take into account the Fresnel relations for transmission of light at a boundary. This fourth factor is contemplated but not discussed in detail herein. These relationships could be determined by a person of ordinary skill in the art, if necessary.

Referring to Fig. 3, in order to satisfy the first three factors discussed hereinabove, the following constraints are assumed.

For a totally internally reflected beam at the coating to fluid interface:

$\theta_2 = \theta_3$

When the index of refraction n_3 outside the coating is 1.0, i.e., when no fluid is present:

$$\theta_2 > \sin^{-1}\left(\frac{n_3}{n_2}\right)$$

and when the light is to be transmitted at the fluid to coating interface, i.e., when fluid is present having an index of refraction n_3:

$$\theta_2 < \sin^{-1}\frac{(n_3)}{(n_2)}$$

Moreover, in order to avoid internal light trapping at the coating to tip element interface:

$$\theta_3 < \sin^{-1}\frac{(n_1)}{(n_2)}$$

Noting further that

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2}\sin\theta_1\right)$$

and that

$\theta_1 = 90° - a.$

The internal reflection angle B (Fig. 3) for light incident at the tip element to coating interface can be expressed as

$B = 90° + \theta_4 - a$

Finally, since

$$\theta_4 = \sin^{-1}\left(\frac{n_2}{n_1}\sin\theta_2\right)$$

by substituting according to the assumed constraints

$$B = 90° + \sin^{-1}\left(\frac{n_2}{n_1}\sin\left(\sin^{-1}\left(\frac{n_1}{n_2}\sin 90° - a\right)\right)\right) - a.$$

Provided the necessary internal constraints are satisfied, B can simply be expressed as

$B = 180° - 2a.$

By way of example only, it has been found that a sensor according to the invention useful for detecting standard aviation fuel known by the designation "JP4" can be constructed using a saphire sensing tip element having a bevel angle 'a' of approximately 45° and an index of refraction on the order of 1.77, coated with a thin polytetrafluoroethylene(PTFE) coating having a relatively constant index of refraction of about 2.1. This sensor tip has been found to be useful for sensing the presence of fluids having an index of refraction from 1.1 to 2.1. and has been found to be particularly desirable for sensing jet fuels having an index of refraction from 1.42 to 1.46, depending upon the age of the fuel.

Of course, it is contemplated that the sensing tip could be be made from any optical quality glass of other material having an appropriate index of refraction and bevl angle. It is also contemplated that coatings other than PTFE may prove to be suitable depending upon the particular fluid sensing application.

Other specific constructions presently contemplated but not yet constructed are set forth in Table I, listing two additional tip element selections for similar sensing conditions.

TABLE I

Tip element material	Glass	High lead content glass
Tip element index of refraction n_1	1.46	1.9
Tip bevel angle 'a'	45°	45°
Coating material	PTFE	PTFE
Coating material index of refraction n_2	2.1	2.1
Fluid index of refraction n_3	1.42	1.42
air n_3	1.0	1.0
B (internal reflection angle)	90°	90°

Using the formulae set forth above, it can be shown that the tip materials listed in Table I should satisfy all internal constraints. That is, when these tip materials are used, light should be transmitted to the fluid when the fluid is present (i.e., n_3 = 1.42) or totally internally reflected for detection when the fluid is not present (i.e., n_3 = 1.0).

It can also be shown using the above formulae that under the same conditions shown in Table I, a hard plastic tip element having an index of refraction n_1 equal to 1.3 will not satisfy the necessary internal constraints. That is, should a hard plastic tip element be used under these conditions it can be shown that no total internal reflection would occur either in the presence of a fluid having n_3 = 1.42 or in the presence of air having n_3 = 1.0. Thus, a hard plastic tip element would not be satisfactory for this particular application since no distinction could be noted between the presence or absence of the fluid.

In this regard, when the coating material is PTFE having n_2 = 2.1 and the tip element bevel angle 'a' = 45°, it can be shown that for any particular fluid and tip ele ment material the exit angle θ_3 must be maintained below 90° in order to distinguish the fluid from air. When θ_3 reaches 90° total internal reflection will occur and no distinction can be made.

It has also been found that by varying the sensitivity of the detector and processing electronics the sensor tip according to the invention can be used to sense the presence of water having an index of refraction of 1.33. Thus, it is further contemplated that when two miscible liquids having distinct indices of refraction are present a distinction between such fluids can be made. Indeed, it is believed that an estimate of the relative percentage of such miscible fluids relative to the total fluid can be made using an analog display. That is, where only one fluid is present a certain light level indication would be expected and in the presence of only the second fluid a distinct reading would be expected. In the presence of a mixture of the two fluids, an analog reading somewhere between those two values can be expected.

A small amount of light entering tip element 15 from sensing tip optical connector 7 is always dispersed over an emission cone depending upon the effective numerical aperture of the sending fiber(s). Consequently, some light is always returned to photodetector 11 based only upon internal reflections of tip element 15 (see Fig. 3, specifically reflection angle B). Advantageously, this low-level of constant return energy is detected by photodetector 11 and can be used to provide a fail-safe monitor of the fluid sensor. The electronics module is can be arranged to constantly monitor the presence of this low-level constant return beam and, in the absence of this constant signal, trigger a status line output indicating a system failure. Failure at any point in the emitter, fiber cables, tip element or photodetector will result in an insufficient constant return beam and will trigger the status alert.

Thus, it will be apparent that the fluid sensor according to the invention advantageously provides safe, accurate fluid sensing in the presence of volatile liquids by positioning all electronics which might cause an igniting spark away from the sensing location. Furthermore, the present fluid sensor reduces the likelyhood of false indications due to the formation of residual fluid film or droplets on the sensor and includes desirable fiber optic technology which is capable of operating at relatively long transmission distances without signal interference.

Moreover, the fluid sensor according to the invention is remarkably compact and light weight and includes the capability of self-monitor sensor performance. To the extent not already indicated, it also will be understood by those of ordinary skill in the art that any one of the various specific embodiments herein described and illustrated may be further modified to incorporate features shown in other of the specific embodiments.

Claims

1. An optical fluid sensor comprising a light emitter, a photodetector for producing a signal from light incident thereon, a sensing tip including a sensor tip element being in optical communication with said light emitter and said photodetector, characterized in that first optical fiber means are connected to said light emitter and to said sensing tip for transmitting light from said light emitter to said sensing tip, and second optical fiber means are connected to said sensing tip and to said photodetector, such that light emitted from said emitter is conveyed by said first optical fiber means to said sensing tip, and light reflected from said sensing tip is conveyed by said second optical fiber means to said photodetector for detection and processing by electronic processing means, and that said sensing tip is provided with a coating impermeable to the fluid sensed and resistant to the formation of fluid film or droplets thereon and presenting the sensing tip surface in contact with the fluid to be sensed when the said fluid 12 present.

2. The optical fluid sensor of claim 1 characterized in that said electronic processing means 12 monitors low-level light continuously received by said photodetector 11 from said sensing tip 15 to provide a self-monitoring system capable of indicating system failure.

3. The optical fluid sensor of claim 1 characterized in that said sensing tip 15 has a sensing surface 14 in contact with the fluid to be sensed when said fluid is present, and said sensing tip 15 being in optical communication with the light source and the photodetector 11 and said sensing tip 15 being dimensioned and configured to receive light from said light source and transmit said light to said sensing surface 14 to be transmitted and lost in the presence of the fluid to be sensed, and being internally reflected and directed to the photodetector 11 in the absence of the fluid to be sensed.

4. The optical fluid sensor of claims 1 and 3 characterized in that the sensing tip coating 14 is disposed over said sensing tip element 15 between said tip element and the fluid to be sensed such that the outer surface of such coating 14 away from said tip element 15 constitutes said sensing surface in contact with said fluid when said fluid is present.

5. The optical fluid sensor of claim 4 characterized in that said sensing tip element 15 has a substantially conical configuration.

6. The optical sensor of claim 5 characterized in that

n_1 = the sensing tip element index of refraction,

'a' = the sensing tip bevel angle, and

n_2 = the coating index of refraction, whereby the sensing tip element internal angle of reflection B is defined by the equation

$$B. = 90° + \sin^{-1} \frac{(n_2}{(n_1} \sin(\sin^{-1} \frac{(n_1}{n_2} \sin 90° - a)))-a$$

7. The optical fluid sensor of claim 5 characterized in that the bevel angle 'a' of said sensing tip element 15 equals 45°.

8. The optical fluid sensor of claim 1 characterized in that said coating 14 of said sensing tip 15 is a thin coating composed of polytetrafluoroethylene (PTFE).

9. The optical fluid sensor of claims 1 characterized in that said sensing tip element 15 is composed of saphire.

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Neu eingereicht / Newly filed
Nouvellement déposé

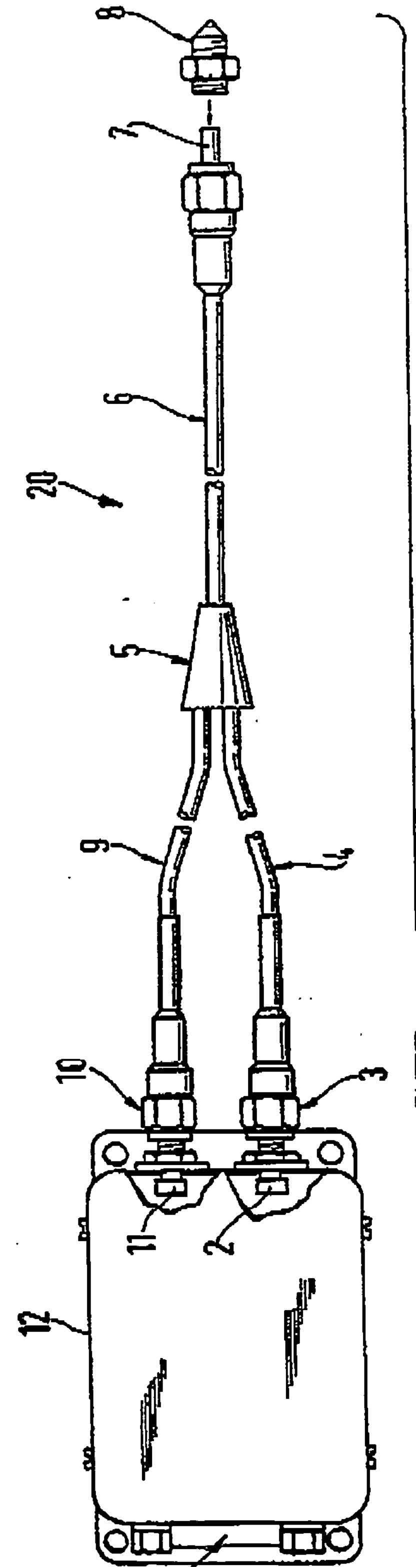

FIG.1

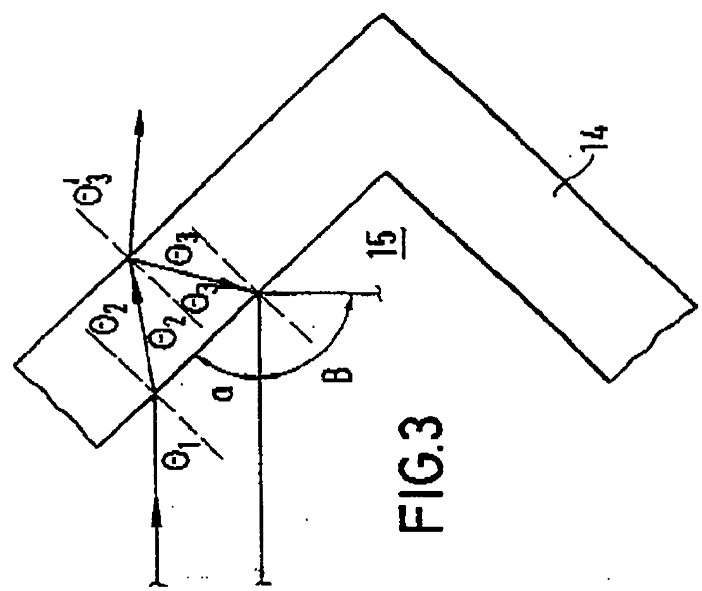

FIG.3

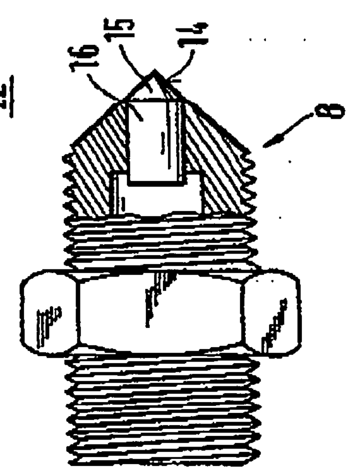

FIG.2

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 87114320.2

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y	EP - A1 - 0 124 415 (ELECTRICITE) * Fig. 1,2; claims 1-5 *	1,3,8,9	G 01 F 23/04 G 01 F 23/22
A		5,7	
Y	US - A - 4 468 567 (SASANO et al.) * Fig. 1-12,16,19,20 *	1,3,8	
A		5,7	
Y	GB - A - 1 508 085 (HECTRONIC) * Fig. 1,2; page 4, lines 8-51 *	1,3,8,9	
A		4,5	
A	US - A - 4 606 226 (KROHN) * Totality *	1,3,5	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	DE - A1 - 3 328 141 (KABEL METAL) * Fig. 1,5; page 9, lines 7-14 *	1,3,5	G 01 F
A	GB - A - 859 104 (THE BENDIX) * Totality *	1,3,5	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	07-01-1988	GRONAU

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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